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Evaluation of Emissivity at 4μ and 10μ and Construction of an 18 Gc/s Radiometer

by

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Introduction

The purpose of this study is to find better ways of evaluation of weather satellite data as well as to propose new satellite instrumentations.

The use of the 18 Gc/s thermal emission for the discrimination between rain clouds and ocean was first discussed in:

Konrad J. K. Buettner, Naturwiss, 50:591, 1963 and

Konrad J. K. Buettner in: W. W. Kellogg, K. J. K. Buettner, and E. C. May, RAND Memorandum RM 4392-NASA, December 1964.

William Kreiss describes the construction of the instrument needed for this task.

The importance of infrared emissivity for satellite data evaluation is discussed in:

Konrad J. K. Buettner and Clifford D. Kern, Science, 142:671, 1963

Konrad J. K. Buettner and Clifford D. Kern, Journal of Geophysical Research, 70:1329, 1965 and above mentioned Rand reports.

Surface temperatures depend on the heat input and on its thermal contact coefficient. Studies on this coefficient have started in order to describe models of surface temperatures.

As the postscriptum indicates, emissivity problems exist also for the 4μ window.

Microwave Study

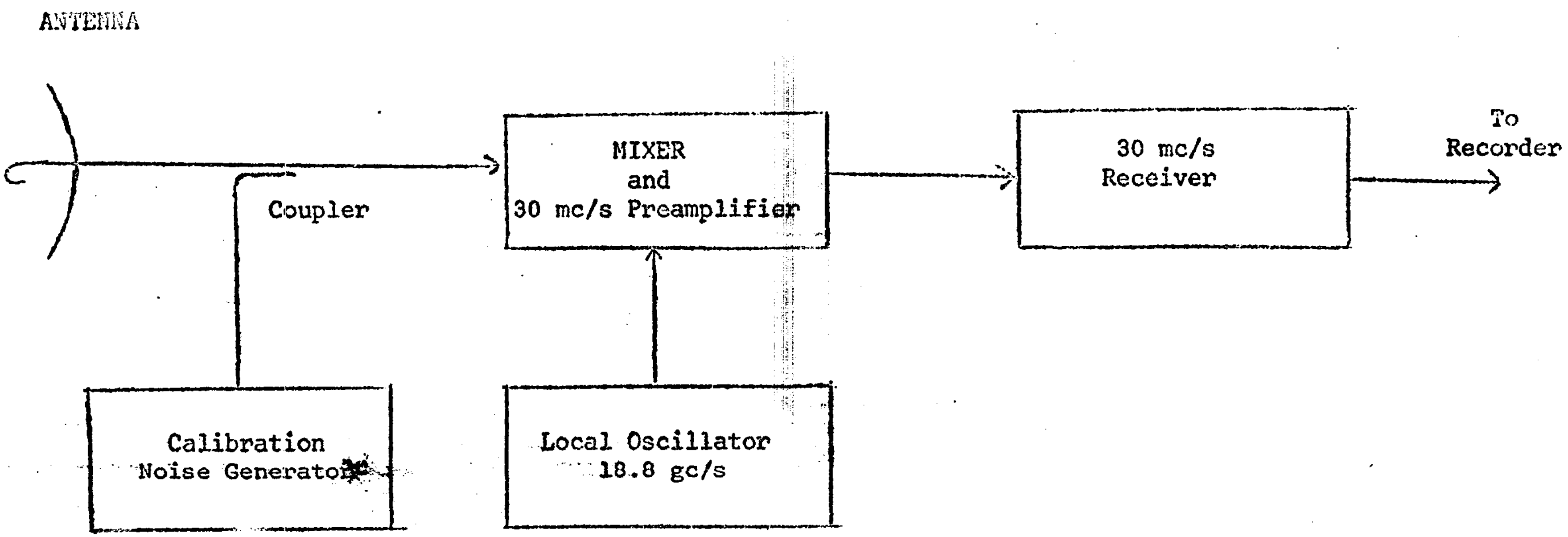
W. T. Kreiss

The first phase of this study has been devoted to the design and construction of a radiometer to support theoretical efforts. At this time, construction has progressed to the final stages, and it is expected that bench testing and calibration will begin within a month. A tentative program of field tests has been drawn up for establishing the operational characteristics of the radiometer

Details of Radiometer Design

For the purpose of this study it was decided that the design of the radiometer be kept as simple as possible with ample leeway for modification and improvement. The initial model is therefore a dual channel, total power radiometer and its major components are shown in the following figure. Although this description uses common terminology it will be clarified in the following discussion.

The operating frequency of this radiometer is specified nominally by the frequency of the local oscillator which is 18.8 gc/s with provision for varying this frequency ± 1 gc/s. The intermediate frequency (IF) of this radiometer is 30 mc/s with a bandwidth of 8 mc/s. Since there is no selectivity preceeding the mixer the instrument responds to signals within two bands (channels) with center frequencies spaced 30 mc/s on either side of the local oscillator frequency of width 8 mc/s. Compared to the frequency of the local oscillator the separation of these bands is small so that response to broadband noise is effectively that of a


ANTENNA
Coupler
Calibration
Noise Generator
MIXER
and
30 mc/s Preamplifier
Local Oscillator
18.8 gc/s
30 mc/s
Receiver
To
Recorder

16 mc/s band centered at 18.8 gc/s.

Total power refers to the fact that the radiometer is not switched alternately between the signal and a reference source, but that the signal is present at all times. As the diagram indicates the calibrator is also connected at all times, however, the calibration signal is switched off except for periodic calibrations. With this arrangement the calibration circuitry contributes about 30°K to the system noise temperature. The range of calibration temperatures is approximately 30-1100°K.

Two antennae are provided for use with this radiometer. A 20db horn antenna to be used for emissivity measurements of various surfaces and a 42 inch parabolic reflector fed with a 10db pick-up horn (combined gain of 50db) for rain field and atmospheric radiation studies.

The receiver provides additional gain at the IF frequency and incorporates the detector circuit. In the output of the detector circuit provision is made for changing the time constant of the radiometer which initially will be of the order of one second. The output of the detector will be monitored with an oscilloscope and recorded on strip chart.

Calculations of the performance indicate that the radiometer should have an overall noise temperature of about 3500°K, output fluctuations of about 5°K and, with the parabolic antenna, a sensitivity of the order of 10^{-10} watts m^{-2}. Determinations of the exact figures will be made during the bench testing phase.

<u>Field Testing</u>

Among the uses for which this radiometer is being built are the observation of rain fields and determination of the emissivities of soils, vegetation, and water. Prior to general field use a number of experiments are scheduled which are intended to establish the operational characteristics of the radiometer. These tests include observing the sun, which at 18.3 gc/s should appear close to 6000°K, the sky radiation from the zenith to the horizon, and a number of materials under controlled conditions.

An interesting possibility for simulating a rain field is presented by the Drumheller fountain on our campus. Due to its multi-nozzle construction a very dense field of droplets with a wide drop size spectrum is produced. It appears to be possible to observe both the thermal radiation emitted by the droplets and the attentuation of signals transmitted through the fountain. Determination of the droplet size spectrum will be obtained by direct means with the aid of personnel in our cloud physics group.

Upon completion and evaluation of these tests an effort to observe thermal emission from natural rain fields will be made.

Infrared Studies

Kristina Katsaros

During the summer months of 1964 the new model of the "emissivity box" was completed (see Buettner and Kern, 1965). It now has an electrically heated aluminum lid with V-shaped grooves, and is spray-painted with Parson's black. A thermostat control keeps the temperature within 0.5°C. The reflecting side mirrors are replaced by an electrically gold-plated brass cylinder, and the two sliding mirrors are likewise of gold-plated brass.

Eastern Washington Emissivity Studies

After the new apparatus was assembled and tested, it was taken on field trips to Ginko National Monument near Vantage on the Columbia River in Eastern Washington and to the Hanford area, farther down the Columbia in Eastern Washington, where emissivities for the 8-12 micron window were measured for various natural surface materials.

Mineral identification for the materials studied at Hanford was supplied by R. E. Brown, Senior Geologist, Geochemical and Geophysical Research Chemical Effluents Technology, Chemical Laboratory, Hanford.

The Hanford materials were in brief described the following way.

Sand dunes South Hanford: well sorted 0.2-0.5 mm grains; 80% quartz, 15% clinopyroxenes and hornblende.

Benson's Ranch Sediments, contain 87.2% Sand (greater than 62μ), 10% silt (62-2μ), 2.8% clay (less than 2μ). Mineral analysis gave sand fraction: 75% quartz, 10% feldspar; silt fractions: 50% quartz, 30% feldspar;

clay fractions: 10% quartz, 20% mica, 20% kaolinite.

Gable Mountain silt: similar to Benson's Ranch silt but coarser, 0.05-1 mm grains; 50% quartz, 30% clinopyroxenes.

Gable Mountain basalt rock: Plagioclase feldspar 35%, augite 30%, basalt glass 30%. The results obtained are given in Tabel I.

TABLE I

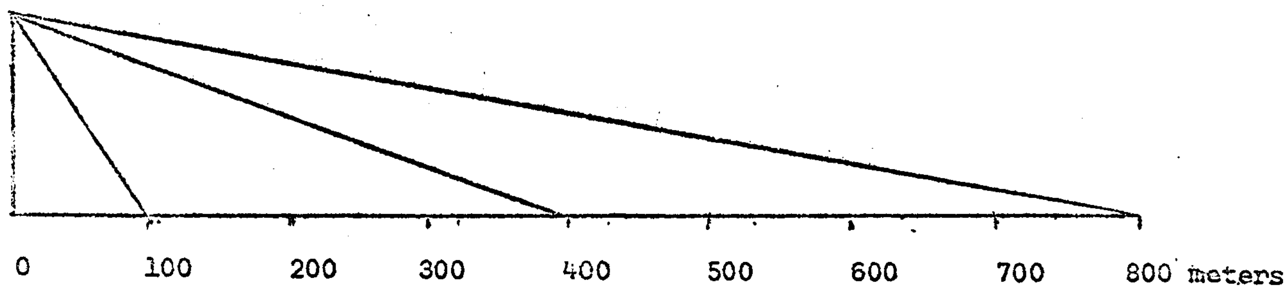
8-12 micron emissivities from Eastern Washington field trips August-September 1964. In the calculations black lid emissivity of 98.5% and gold mirror emissivity of 2% were used. Emissivity and standard deviation of the number of readings taken are given. The readings were all taken with the emissivity box in the same spot; thus variations between readings represent human and instrumental uncertainties rather than sample variations.

Ginko area, August 26, 27 1964	Em.	St. Dev.	Number of Readings
Ginko National Monument, dry grass and leaves, natural surface	99.1	0.65	8
Same as above with vegetation scraped off	99.5	0.39	4
A red lava rock with leichen growing on it	99.2	0.63	4
Sand dune near Wanapum Dam	97.4	0.73	10
Hanford, September 3, 4 1964			
Sand dunes south of Hanford	97.4	0.97	10
Sand dunes south of Handord, different site	94.6	1.4	9
Benson's Ranch sediments, undisturbed	98.4	0.67	10
Benson's Ranch sediments, top soil scraped off	98.5	0.63	7
Gable Mountain silt, top soil scraped off	96.7	0.80	4
Gable Mountain basalt rock	96.1	0.50	5
Neighboring broken up basalt rock, large cavities between them	Very close to 100% estimated from record.		
Kame and Kettle, glacial deposits near Columbia River, some vegetation	>99% estimated from record.		

Dependency of Radiant Power on viewing angle

As a parenthesis I would like to mention an interesting observation from the visit to Hanford. The 8-12 micron Barnes radiometer was taken to the top of a 400' tower and pointed to circular arcs marked on the ground 100 m apart to the North of the tower. The terrain is very uniform, level ground covered with short grass, which was dry in September, and small sage brush. As the radiometer viewing point advanced outwards from the tower the equivalent black bo[illegible] temperature decreased markedly. This was repeated several times with same result (see fig. 1). Calculations show the atmospheric effect due to increased path length to be negligible. (Air temperature averaged 85°F, dewpoint temperature averaged 43°F during time of measurement, 1500 P.S.T.) The observed temperature decrease could be due to the radiometer viewing different parts of the bushes and grasses as the angle increases. Close to the tower more rocks and gravel are being viewed than further out, and at this time they are undoubtedly warmer than the vegetation; but the temperature variation is 8°C, which is large if we compare it with temperature gradients of 2°C found by Marlatt (2) on a clump of grass at Pawnee Grassland in January 1965. The significance of the influence of the viewing angle for satellite determinations of comparable surface temperatures may need further consideration.

Figure 1. Equivalent black body temperature as observed from top of 400' tower.



1.	44.0	44.0	40.5	39.5	37.5	37.0	36.8	36.0
2.	--	43.8	40.5	38.5	36.5	36.0	35.5	35.0
3.	43.5	43.0	40.5	40.8	37.5	37.0	36.5	35.5

Death Valley - Amargosa Emissivity Studies

In January 1965 the Barnes IT-2 was recalibrated and the gold mirrors reguilded in anticipation of a field trip to Death Valley with a group from Colorado State University under William Marlatt working under NASA contract.

The reflectivity of the gold mirrors was determined with the Barnes using a black body cavity of melting ice and "looking" with the Barnes at the cavity direct and via the gold mirror, which was heated to various temperatures. The goldplate emissivity was found to be 1.7%. (Spectrometer measurements will not be accurate since the brass mirrors are not optically flat.)

The participation in the Death Valley-Amargosa Desert study gave the results given in Table II. The geologic names have been supplied by a geologist at this department, K. Bennington. The characterizations were given after only a superficial look at each sample. Marlatt is having the samples analyzed spectrographically, so the names are given only for purpose of recognition.

We had intended to obtain emissivities for 10-11 micron as well as 8-12 micron areas, using a C.S.U. Barnes with 10-11 filter. The resolution on C.S.U. recorder was not satisfactory for emissivity determinations, but in three cases the data seemed fairly good, so they were included.

TABLE II

Emissivities obtained at field study under William Marlatt of Colorado State University in Death Valley, California and neighboring Amargosa Desert, Nevada, February 12-19, 1965. Laboratory emissivity results on samples from the same areas (April 1, 15, 1965). For these calculations black lid emissivity of 99% and gold mirror emissivity of 1.7% were used.

Material	8-12 Micron Field			Laboratory			10-11 Micron Field		
	Em.	St. Dev.	Number of Readings	Em.	St. Dev.	Number of Readings	Em.	St. Dev.	Number of Readings
Devil's Golf Course Mudflat (field and laboratory work not exactly same material.)	97.6	0.38	11	99.4	0.34	2			
Salt Pool, probably more KCl than NaCl.	96.7	1.05	8	97.2	0.56	16			
Red Lava Rocks near Artist's Drive, 3-5 cm diameter. Angular, weathered, scoracious lava rocks with fine whitish sand between.	96.9	0.56	5	99.3	0.35	4	95.4	1.03	6
Alluvial fan near Artist's Drive, altered lava, angular.	91.4	1.35	8	97.9	0.41	11	95.8	0.95	6
Gray Clay from Badwater area, a friable pumice, weathered and altered.	99.0	0.21	5	99.2	0.17	4			
Badwater area recemented debris of lava types.	96.9	0.65	12	98.1	0.48	12			
Black basalt rock. One big rock for field study, a couple of rocks of about 10 cm diameter, barely filling cylinder of emissivity box for laboratory work.	96.3	0.64	8	96.6	0.72	10	96.3	0.78	6
Amargosa float of scoracious pebbles of lava rock, rounded, few angular, 1-5 cm diameters, fine silt between field study site material.	97.4	1.40	3	97.9	0.20	10			
Material from banks of dry river-bed northeast of site.				97.3	0.57	14			

Material	Laboratory Em.	Laboratory St. Dev.	Number of Readings	
The following are materials collected on a hill opposite Horseshoe Motel on U.S. 95, Beatty, Nevada				
Yellow rocks, well weathered lava, angular 3-5 cm, fine sand between.	98.3	0.62	8	
Red rocks, rhyolite.	97.6	0.35	9	
Green rocks, shattered chert, silicious argelite, friable angular 0.5-1.0 cm diameters.	99.4		1	(looks very black on all records)
Gray rocks. Chert, silicious rocks, fragments of red scoria, very angular, 2-3 cm diameter.	90.5	1.01	13	
Repeat.	97.0	0.81	3	
Rearranged.	91.5	0.17	3	
Special type of gray rock on top.	96.5	0.85	3	
Pumice from surface mine, well weathered.	99.6	0	1	
Pumice after wetting and redrying, developing a harder surface with cracks in it.	99.4	0	1	

Discussion of IR Emissivity Results

There are quite large deviations in a few cases between laboratory and field work. One has to consider that by the time the sample has been shipped and placed in the sample pan it may not really represent the natural surface anymore. The rocks on the desert develop a special top surface through weathering called "desert varnish" which may have a different emissivity than the bottom surface. For the Amargosa material the silt had spread over the rocks in transportation and brushing and washing the top rocks gave the following change in emissivity.

	Em.	St. Dev.	Number of Readings
Amargosa materials	97.9	0.20	10
Amargosa material, other sample	97.3	0.57	14
Amargosa material, brushed off	98.5	0.52	6
Amargosa material, washed clean on top	98.6	0.41	4

Since I used different values of the emissivity of the black lid (EB) and the gold mirror lid (EM) for the Eastern Washington and Death Valley studies the effect of lid emissivities on calculated surface emissivity is given here. The apparatus was unchanged. It was only the assumed values of EB and EM that were changed. One set of data (Monterey Sand) was run on the computer with different values of EB and EM. As can be seen from the following data a small change in EB and EM has only a slight effect on calculated surface emissivity.

EB%	EM%	ES%
96.00	1.00	92.15
96.00	4.00	92.03
97.00	3.00	91.94
98.00	2.00	91.85
99.00	1.00	91.75
99.0	4.00	91.63

The large deviations of the "gray rocks" emissivity obtained in the laboratory by just shaking the pan with the sample, shows that spot determinations of emissivity cannot without care be used as regional averages. For a gravel material it undoubtedly is dependent on whether the radiometer is viewing a cavity between pebbles or a larger flat rock.

Some interesting results were obtained in the laboratory in regard to emissivity of sodium chloride. Coarse grained salt (1-2 mm grains) of rock-salt was relatively black in the "window" while finer grained salt was highly reflective. This is undoubtedly a parallel to the process of diffuse reflection of short wave radiation by snow, which is transmitting in short wavelengths as NaCl is in the IR. The results are shown in Table III together with data on gypsium and potasium chloride.

TABLE III

Emissivities in the 8 - 12 micron window obtained in the laboratory April 27, 28, 1965. Black lid emissivity of 99% and gold mirror emissivity of 1.7% used in the calculations.

	Em.	St. Dev.	Number of Readings
Sodium chloride, regular table salt, 270-360μ cubic crystals.	72.5	0.5	6
Sodium chloride, Baker's reagent, 100-400μ cubic crystals.	57.0	1.3	5
Coarse sodium chloride, 2-5 mm crystals, milky surface.	98.8	0.01	2
The above rinsed and dried, shiny crystals.	97.5	0.5	5
Coarse sodium chloride ground to 50-1000μ grains.	92.1	1.2	8
Coarse sodium chloride ground to 10-400μ grains.	85.0	0.7	6
Calcium sulphate, Baker's reagent powder,	98.8	0.3	2
Calcium sulphate wetted and dried in oven, yellowish surface.	95.6	0.4	6
The above with the yellowish surface scraped off.	92.9	0.4	6
Potassium chloride, Baker's reagent, crystal.	50.4	1.1	6
Calcium chloride, anhydrous, 4 mesh reagent.	79.4	0.9	6
Potassium sulphate, powder reagent.	89.2	0.8	5

Thermal Contract Coefficient Measurement

In connection with emissivity measurements we have had to worry about the effect of heating of the surface as it is exposed to the black lid of the emissivity box. The reader is referred to Carslow and Jaeger (3) p. 56 for the theoretical background. We consider the earth's surface to be a semi-infinite solid of initial temperature zero. The flux of heat is supplied to the top surface ($x = 0$) as a prescribed function of time, in our case solar radiation, which is considered constant. The surface to be studied is observed with a Barnes IT-2. The net heat input is determined as total solar radiation minus sky radiation minus albedo. The total incoming radiation is read by the unshaded pyrheliometer, the sky radiation by blocking out the sun and the albedo by turning the pyrheliometer upside down. The solution for the temperature change at the earth's surface is

$$\Delta T = \frac{2Q\sqrt{t}}{\sqrt{\pi\lambda\rho c_p}} \qquad (1)$$

ΔT temperature change, t time increment, Q net heat input, λ = thermal conductivity, ρ = density, c_p = specific heat.

With T, t and Q measured, $\sqrt{\lambda\rho c_p}$, the so called "thermal contact coefficient" may be determined. A computer program for this calculation was written by one of our graduate students, Phil Duchemin, as a term project.

Two sets of data were used, one obtained at Benson's Ranch, Hanford, and one on gravel material outside the Atmospheric Sciences Department, University of Washington campus. The units of the "thermal contact coefficient" are in cal cm^{-2} deg^{-1} $sec^{-1/2}$.

	Thermal Contact Coefficient	St. Dev.
Benson's Ranch silt	1.31×10^{-2}	1.1×10^{-3}
Atmospheric Sciences gravel	3.1×10^{-2}	0.5×10^{-2}

Comparing the above with the thermal contact coefficient of granite and sand as determined from values of λ, ρ and c_p given in the Handbook of Physics and Chemistry we see that the results are reasonable. Granite gives approximately 5×10^{-2}, sand approximately 1.4×10^{-2} same units as above.

This composite constant can thus be determined with this simple experimental set-up. For further investigation a more reliable heat source than the sun in Seattle should be developed. The outgoing IR radiation does of course increase as the temperature increases. This was not taken into account in the calculation, but the results show the effect. Neither was the emissivity considered when using the Barnes readings of temperature.

Future Plans

We are at present considering the effects of waves and oil on a lake or ocean surface in changing the equivalent black body radiation, which would be observed by a satellite above. The effect of the sea-state is due to water and oil emissivities being functions of the angle of emission (and not following Lambert's cosine law). Thus there would be a greater fraction of sky reflection in a signal from a rough sea.

In addition the sky IR intensity is a function of zenith angle and of course cloud conditions. The effect is undoubtedly small, but according to G. C. Ewing (4) the requirements on remote sensing of ocean surface temperatures are quite stringent.

The investigation will be done by computer models, and by experimental determinations of reflectivity of pure and salt water, and of various oils occurring on the ocean surface. The reflectivities will be found as functions of wavelengths and incidence angle on Beckman IR-8 Spectrograph with special attachments. The radiation temperature of the sky at various zenith distances can be obtained for the 8-12 micron window with the Barnes IT-2.

Postscriptum

Some New Ideas for NIMBUS use

Konrad J. K. Buettner

After O. Reinkober (Ann. Physik, 34:343, 1911) quartz is quite permeable for $\lambda<4.8\mu$ with a reflectivity of a few per cent. Quartz sand and quartz dust should therefore for $\lambda\sim4\mu$ behave like snow to visible radiation. Its 4μ albedo could be substantial. The high albedo at 4μ is expected to increase with the degree of dispersion of matter contrary to the behavior of 9-10μ where Reststrahlen causes the high albedo only as long as the particles are large compared to λ. Note that at 9-10μ quartz is not permeable at all.

A similar effect can be anticipated for all finely dispersed materials of sufficient transparency around 4μ, e.g. salts and snow. Whereas the 8-12μ deviation stems mainly from a sharp but small quartz reststrahlen band near 9.5μ, the 4μ deviation would more or less cover the whole window.

The 4μ night picture of Western Europe, made by NIMBUS I, has been rechecked. Discernible are the Ruhr Valley (1-2 grey shades) which forms a triangle, the Cologne area south of it, the middle Rhine (somewhat uncertain), the Belgian industry area (1 grey shade), and the Hartz Mountains.

With our present lack of data on 4μ emissivity it would be futile to speculate about the role of ε in this case. Cities at clear nights are 2-3°C warmer than the country. This difference, measured at eye level, is probably larger at the surface since city climatic stations will rarely enjoy a perfectly free exposure to outgoing radiation. Maybe a difference of 5°K can be accounted this way.

We may add to this the effect of smog and inversion. If the inversion layer is 10°K warmer than the ground and if its 4μ transmissivity is 50% we would gain another 5°K for the observed satellite temperature.

Direct test using PbSe conductive cells, filter for 4μ, and the emissivity box are planned. In the meantime, however, data of ε can be estimated from NIMBUS daytime 4μ pictures.

Figure 1 of "Nimbus I High Resolution Radiation Data Catalog and Users Manual," Vol. I. shows Central America at daytime via the 4μ filter. Most sealevel surfaces will emit as 300°K bodies or 0.2 watt m^{-2} $ster^{-1}$. The sun if fully and diffusely reflected would create about 1.6 W m^{-2} $ster^{-1}$. The sum of both signals is recorded: Signal = $\varepsilon B\ (T_{BB}) = (1-\varepsilon)$Sun.

All open waters except for the glare under the sun are dark, since under these angles the water reflex is minute. High clouds show a moderate brightness caused exclusively by solar reflex since their emission is smaller than 0.05.

Exceedingly bright are sea level deserts, jungles, and low clouds, both from a combination of solar reflex and emission. The areas mentioned are:

1. Jungles both sides of the Orinoco, 5°N 68°W; the Magdalena Valley at 7°N 74°W; and the upper Amazon basin.

2. The Guajira Desert at 12°N 72°W.

3. Low clouds north of Colombia and S.E. of hurricane Dora.

Open lowlands such as Cuba reflect more than the ocean but less than jungle, sand or low clouds.

The ε of snow cannot be guessed this way: Some daytime runs of Antarctica and Greenland are on record. The sun is of course only a few degrees above the horizon. But these areas show very low signals.

This work will be going on after detailed information on NIMBUS data has arrived.

More daytime data of future NIMBUS flights are wanted.

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